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Effects of supplemental LED lighting and biofertilizer on yield and fruit quality of Japanese strawberry cultivars in Indonesia

Abstract. Growing strawberries in soilless substrates in the greenhouse relies on fertilizers and supplemental light to boost yield and fruit quality. The research evaluated the properties of the biofertilizer and its effectiveness on the yield of Japanese strawberry cultivars Nanatsuboshi and KS-75 under controlled greenhouse conditions, with and without light-emitting diodes (LED) as supplemental light. The cell viability and plant-growth-promoting properties of a liquid consortium biofertilizer consisting of nitrogen-fixing bacteria and phosphate-solubilizing microbes, were characterized. Laboratory analysis confirmed the biofertilizer's composition, and a greenhouse experiment using a completely randomized design tested treatments of biofertilizer, LED, and their combination. The biofertilizer contained specific phytohormones and organic acids, with bacterial and fungal populations exceeding 10^7 and 10^5 CFU/mL, respectively. The 3-month greenhouse experiment showed that the biofertilizer, LED, and their combination reduced fruit number and weight in the strawberry cultivar Nanatsuboshi but increased them in KS-75. However, the total fruit weight of Nanatsuboshi was higher than that of KS-75 due to its larger size. The treatments did not increase the fruit total soluble solids (TSS). These findings indicate that KS-75 exhibited a stronger response to biofertilizer and LED treatments than Nanatsuboshi.

Keywords: Biofertilizer properties · Fruit number · Fruit weight · Light-emitting diodes · Total soluble solids

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Introduction

Strawberries (*Fragaria* × *ananassa* Duch.) are temperate crops that have adapted to high-altitude tropical regions, such as those found in Indonesia. Their economic importance drives increasing Indonesian demand for sweet, large, and appealing fruit. Most cultivars in Indonesia originated from seeds imported from the United States and later evolved into local varieties, whereas only a limited number of Japanese strawberries are grown there.

The cultivar, climate, and cultivation methods strongly influence the fruit's TSS. Local strawberries typically have a sweetness level of 5-8 °Brix (Hindersah et al., 2023; Romiyadi & Putri, 2024), which is considered sour, whereas Japanese strawberries range from 10-14 °Brix (Ikegaya, 2024). In general, optimal temperatures for strawberry growth are 18-25 °C, and optimal relative humidity is 60-69%. A temperature difference of 10-12 °C between day and night enhances sugar accumulation (Wu et al., 2021). High temperatures and humidity impede flower development, hinder pollination and fruit set, and reduce yield and quality (Muneer et al., 2017).

Greenhouse cultivation offers a promising method for controlling microclimates and enabling year-round production. Because natural sunlight varies throughout the day, supplemental artificial lighting is essential. LED technology provides high light intensity, adjustable wavelengths, and low heat emission. LEDs emit specific wavelengths, including red and blue, that meet plants' photosynthetic needs and influence photosynthesis, morphogenesis, and flowering. In subtropical regions, cultivating strawberries in greenhouses under LED lighting increased leaf chlorophyll levels, vegetative growth, above-ground dry matter, and fruit production compared with those without LED (Choi et al., 2015; Nakayama, 2025; Hwang et al., 2025). The beneficial effects of red and blue LED on the yield and total soluble solids of American strawberries grown in conventional greenhouses in Indonesia have been documented (Adrian et al., 2024). However, similar research on Japanese strawberries is lacking.

In greenhouses, strawberries are often grown in soilless substrates, simplifying management and reducing pest and disease incidence. Most growers in Indonesia still depend on chemical fertilizers for soilless-based cultivation. Biofertilizers provide an eco-friendly and cost-effective source of nutrients. They typically contain nitrogen-fixing bacteria (NFB) and phosphorus-solubilizing microbes (PSM). The NFBs convert atmospheric N_2 into ammonia, NH_3 (Pajares & Bohannan, 2016), which is further transformed into available ammonium and then nitrate (Longepierre et al., 2022). Meanwhile, PSMs release organic acid to convert inert inorganic phosphorus to available one and hence increase its bioavailability (Yadav et al., 2015).

Beneficial bacteria *Azotobacter*, *Azospirillum*, and *Acinetobacter* (endophytic N-fixer), and *Pseudomonas*, have been reported to promote plant growth, enhance plant health, and increase strawberry yield (Hosseini et al., 2022; Morais et al., 2019). The positive impact of *Penicillium* and *Trichoderma* on strawberry growth was reported (Fitriatin et al., 2025). Many of these microbes also synthesize phytohormones that are involved in strawberry plant development (de Andrade et al., 2019; Rueda et al., 2016). Biofertilizer application in strawberries enhanced juice content, total soluble solids, and total sugar (Kumar et al., 2019). However, data on the response of Japanese strawberry cultivars to beneficial bacterial inoculation in tropical regions are limited.

Integrating lighting and biofertilizers provides a synergistic solution to optimize yields and fruit sweetness in Japanese strawberry production in tropical regions. Nonetheless, the microbial composition and metabolite content of biofertilizers determine their effectiveness in boosting plant yield. This study aimed to characterize the plant-growth-related properties of the biofertilizer consortia and evaluate their effectiveness on the cv. Nanatsuboshi and KS-75 strawberry yields and sweetness under controlled greenhouse conditions, with and without LED lighting. This research presents the first report on the application of biofertilizers for growing Japanese strawberries in an environmentally controlled greenhouse in Indonesia.

Materials and Methods

The laboratory analysis was carried out in June 2024. A pot experiment was conducted in the environmentally-controlled greenhouse at the Faculty of Agriculture, Universitas Padjadjaran, from August to November 2024.

Biofertilizer Characterization. The consortia biofertilizer consisted of heterotrophic-aerobic *Azotobacter chroococcum*, *A. vinelandii*,

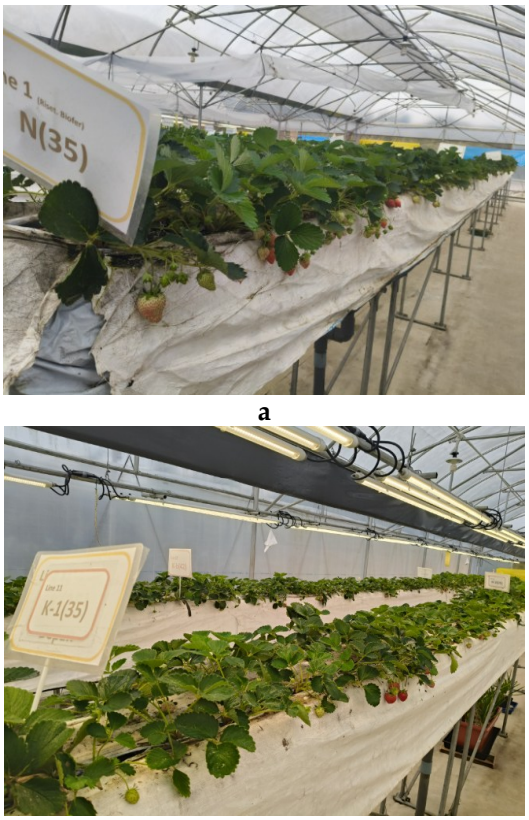
Acinetobacter sp., *Azospirillum* sp., *Pseudomonas cepacia*, and *Penicillium* sp. Microbes were scaled up separately in 30 L of molasses-based growth media within a 45 L bioreactor. The initial inoculum concentration in the media was 5%, and the culture was incubated for 3 days at room temperature with agitation at 130 rpm. All microbial cultures were mixed in a balanced ratio before bottling. PT Pupuk Kujang provided the biofertilizer in collaboration with the Faculty of Agriculture, Universitas Padjadjaran.

Population counts and metabolite analyses in the biofertilizer were performed one month after bottling. The population of each microbial strain was quantified in specific media using the serial dilution and plate count method (Ben-David & Davidson, 2014). A total of 0.1 mL of the microbial suspension was taken from the diluted BF, poured onto the sterilized plates, and mixed with 20 mL of the media. The plates were incubated at 30 °C for 3 days for bacteria and 5 days for *Penicillium* fungi. Each colony with a diameter of 1 mm or more was counted. The microbial counts were replicated three times.

The opportunistic pathogen *Escherichia coli* and *Salmonella* spp. were enumerated using the Most Probable Number method (Weaver et al., 1994). Indole-3-acetic acid (IAA) was measured by spectrophotometer after extraction with Salkowski's reagent (Patel et al., 2018), while gibberellins (GA3, GA4 and GA5) and cytokinins (zeatin and kinetin) were determined through HPLC with mobile phase of acetonitrile/water (50/50; v/v) and a flow 1.0 ml/min; the detection was performed by a UV detector set at 205 nm (Macías et al., 2014). Specific organic acids, including lactic, oxalic, citric, and acetic, were measured by high-performance liquid chromatography (Risanti et al., 2025).

The strawberry cultivars used in this study were Nanatsuboshi and KS-75, which had been grown in beds for one year. The growth medium in the trays on the raised beds consisted of a 9:9:1 volume ratio of coco peat, rice husk, and peat moss. Both strawberry cultivars were imported from Okinawa prefecture, Japan, and provided by the Japan Premium Vegetable Project in collaboration with the Faculty of Agriculture, Universitas Padjadjaran.

Greenhouse Experiment. The greenhouse temperature was maintained at 20 °C at night and 25-30 °C during the day, with a relative humidity of 60%. LEDs with a wavelength of 400-800 nm were installed 60 cm above the cultivation beds (Figure 1), and automatically turned on daily from 4:00-6:00 pm and 6:00-8:00 am, and when outside sunlight was less than 300 W/m².



a

b

Figure 1. The strawberries cv Nanatsuboshi grown with natural light (a) and KS-75 cultivars grown in the raised bed under LED (b)

Photosynthetic photon flux density (PPFD) was recorded every 5 minutes using quantum photosynthetically active radiation sensors. Data were stored in a Decagon EM50 data logger. During the experiment, the average PPFD under natural and LED light were 179.62 and 166.10 mol/m²/s (Table 1), while the average daylight integral (DLI) values were 15.52 and 14.35 mol/m²/day (Table 2).

Table 1. The photosynthetic photon flux density during the experiment

PPFD (mol/m²/s)	Non-LED	LED
Sum	16345.60	15115.46
Minimum	94.01	115.79
Maximum	222.19	207.14
Mean	179.62	166.10

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Table 2. Daylight integral during the experiment

DLI (mol/m²/day)	Non-LED	LED
Sum	1412.26	1305.98
Minimum	10.00	8.12
Maximum	17.90	19.20
Mean	15.52	14.35

Monthly PPFD and DLI under LED and non-LED areas were shown in Figure 2.

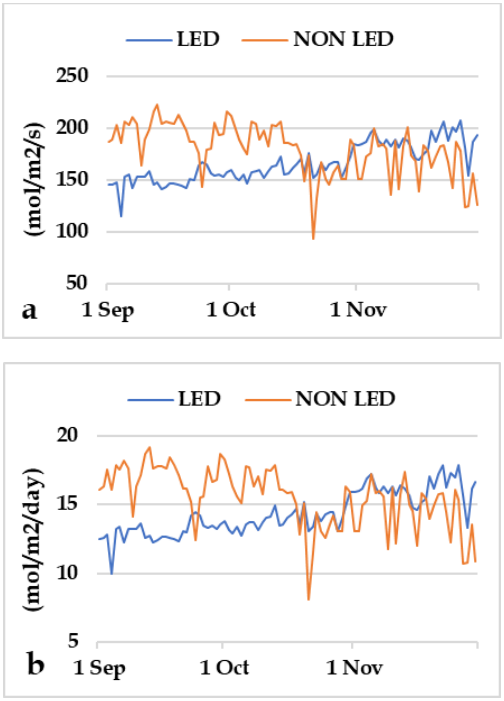

Figure 2. The dynamic of photosynthetic photon flux density (a) and daylight integral (b) from September to November 2024 under LED and natural (non-LED) lighting

Experimental Design and Implementation. The experiment was conducted using a randomized complete block design to test one independent factor with four treatments and five replications. The treatment factors included A) natural lighting without biofertilizer, B) LED lighting without biofertilizer, C) natural lighting with biofertilizer, and D) LED lighting with biofertilizer. Each treatment was placed in 5 trays, each containing seven plants.

The strawberry cultivars used in this study were Nanatsuboshi and KS-75, which had been grown in beds for one year. The growth medium on the raised beds consisted of coco peat, rice husk, and peat moss (9:9:1; v:v:v). Both cultivars were imported from Okinawa prefecture, Japan, and provided by the Japan Premium Vegetable Project in collaboration with the Faculty of Agriculture, Universitas Padjadjaran.

Plant nutrients were supplied through fertigation. The nutrient solution was prepared by mixing the A and B nutrient solutions with 3% citric acid in the specified composition. The A solution contained 1,200 ppm $CaNO_3$, 350 ppm KNO_3, and 40 ppm Fe; the B solution contained 800 ppm $MgSO_4$, 300 ppm KH_2PO_4, 50 ppm K_2SO_4, 10 ppm $MnSO_4$, 10 ppm boric acid, 5 ppm $CuSO_4$, 2 ppm $(NH_4)_2MoO_4$, and 5 ppm $ZnSO_4$. All nutrient solutions were placed in separate containers. The nutrient solution was applied at an average EC of 0.5-0.7 dS/m and a pH of 5.7. The daily fertigation was adjusted to deliver 50 mL over 10 minutes per hour from 6 am to 4 pm.

Biofertilizer at a 5% (v:v) concentration and 20 mL volume was applied to the leaves every two weeks for two months. Plants without fertilizer were sprayed with the same volume of water. Before biofertilizer application, the plants were in the fruiting stage, and no fruits or flowers were removed. Natural pesticides were applied regularly, 2–3 times a week, to control aphids and mites. The caterpillars that sometimes attack the leaves were manually removed and squashed. The experiment maintained three crowns per plant and eight leaves per crown. All runners and side roots were removed. The mature fruits were harvested three times a week.

Parameters and statistical analysis. The number of fruits, their total weight, and the total soluble solids (TSS) of both the fruit tip and the intact fruit were measured. The fruit tip is the low part of the fruit; one-third of the height of the fruit is cut to get the fruit tip. The fruits were weighed using a digital scale (1000 HPS2, Sojikyo, Japan), and TSS was measured with a refractometer (PAL-1, Atago, Ltd., Tokyo, Japan). All data were analysed using one-way analysis of variance (ANOVA) at $p < 0.05$. The means were compared using the Tukey Honestly Significant Difference (HSD) test at $p < 0.05$. Statistical analyses were performed using SPSS version 25.

Results and Discussion

Biofertilizer Properties. All microbes inoculated into molasse-based liquid biofertilizer were recovered using specific growth media (Table 3). The biofertilizer contained a low population of opportunistic pathogens, *E. coli* and *Salmonella*

spp., each at <3 MPN/mL. The phytohormones, including IAA, gibberellins, and cytokinins, were present in biofertilizer (Table 3). Lactic, oxalic, and acetic acids were found in the biofertilizer, but citric acid was not detected.

The number of microbial populations in a biofertilizer is the primary factor determining its quality and effectiveness. The populations of bacteria and fungi were more than 10^7 and 10^5 CFU/mL, respectively, which complies with the Indonesian Ministry of Agriculture Regulation No. 261 of 2019 about biofertilizer. The liquid media support heterotrophic microbial growth, as molasses provides 29-40% sucrose, 4-14% glucose, 0.5-4.5% protein, 0.3-1.5% amino acids, phosphorus, potassium, and other nutrients (Jamir et al., 2021). Heterotrophic microbes in biofertilizer metabolize saccharides for energy and carbon, as well as proteins and amino acids for nitrogen sources.

Rhizobacteria can produce IAA through both tryptophan-dependent and tryptophan-independent pathways. Notable examples of rhizobacteria that produce IAA without external tryptophan include *Azotobacter*, *Pseudomonas* (Ahmad et al., 2005), and *Acinetobacter* (Lin et al., 2018). In contrast, most *Azospirillum* species rely on exogenous Trp for IAA biosynthesis (Carreno-Lopez et al., 2000). In this study, *Azotobacter*, *Pseudomonas*, and *Acinetobacter* mainly contributed to IAA production in the culture, as no external Trp was added.

The presence of GA and CK in biofertilizer reconfirmed that Azotobacter, Azospirillum, and Pseudomonas can synthesize both phytohormones, as discussed elsewhere. Molasses provides disaccharides and other nutrients for bacterial growth and the production of phytohormones, which are then released into the surrounding medium (Hindersah et al., 2020). In this study, the reactor headspace and continuous agitation maintain an aerobic environment during biofertilizer production. All microbes in the biofertilizer exhibit heterotrophic and aerobic metabolism rather than fermentation, resulting in a low organic acid content.

Strawberries Yield. Biofertilizer, LED, and their combination significantly reduced the number of fruits per plant in Nanatsubohsi but increased it in KS-75 (Table 5).

Table 3. Microbial composition of the liquid consortia biofertilizer

Microbes	Methods	Growth Media	Population	Unit
A. vinelandii	TPC[1]	Vermani Agar	2.16×10^7	CFU/mL
A. chroococcum	TPC	Ashby Agar	1.37×10^7	CFU/mL
P. cepacia	TPC	Pikovskaya Agar	9.74×10^7	CFU/mL
Acinetobacter	TPC	Tryptic Soy Agar	1.55×10^9	CFU/mL
Azospirillum sp.	TPC	Okon Agar	3.85×10^7	CFU/mL
Pencillium sp.	TPC	Pikosvkaya Agar	1.21×10^5	CFU/mL
Escherichia coli	MPN[2]	EMBA[4]	< 3	MPN/mL
Salmonella sp.	MPN	SSA[5]	< 3	MPN/mL
Patogenicity	HS Test[3]	Tobacco plants	Negative	-

[1]Total Plate Count, [2]Most Probable Number, [3]in-planta hypersensitive test, [4]Eosin Methylene Blue Agar, [5]Salmonella Shigella Agar.

Table 4. Phytohormones and organic acid composition of liquid consortia biofertilizer

Metabolites	Concentration (mg/L)
IAA	34.01
GA3	167.09
GA4	38.07
GA5	43.90
Zeatin	198.23
Kinetin	21.86
Lactic acid	2.73
Oxalic acid	4.97
Citric acid	nd[1]
Acetic acid	32.51

[1]Not detected

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Table 5. Fruit number of 'Nanatsuboshi' and 'KS-75' strawberry in response to different supplemental LED lighting and biofertilizer treatments over three months of observation

Treatments	Fruit number per plant in each month					
	Nanatsuboshi			KS-75		
	1st	2nd	3rd	1st	2nd	3rd
Control (without BF[1], natural light)	4.0 b	2.8 a	4.8 c	1.0 a	1.0 a	1.5 a
BF, natural light	2.7 a	2.5 a	3.5 ab	1.6 ab	1.3 a	1.6 a
Without BF, LED	2.3 a	2.0 a	3.0 a	1.5 a	2.2 b	2.7 b
BF, LED	2.7 a	3.5 a	4.0 b	2.3 b	2.7 b	2.3 b

Mean values (n=6) followed by different letters in the same column were significantly different according to the Tukey HSD test at $p < 0.05$. [1]Biofertilizer

Table 6. Fruit weight per plant of 'Nanatsuboshi' and 'KS-75' strawberry in response to different supplemental LED lighting and biofertilizer treatments over three months of observation

Treatments	Fruit weight (g/plant) in each month					
	Nanatsuboshi			KS-75		
	1st	2nd	3rd	1st	2nd	3rd
Control (without BF[1], natural light)	39.5 a	26.6 ab	43.7 b	8.6 a	7.4 a	9.6 a
BF, natural light	37.9 a	24.3 a	31.6 a	13.7 b	12.5 b	14.3 ab
Without BF, LED	23.6 a	21.5 a	31.3 a	13.1 b	15.9 b	14.8 ab
BF, LED	26.7 a	32.5 b	39.7 b	19.6 c	19.7 c	17.5 b

Mean values (n=6) followed by different letters in the same column were significantly different according to the Tukey HSD test at $p < 0.05$. [1]Biofertilizer

Table 7. Total fruit number and fruit weight of 'Nanatsuboshi' and 'KS-75' strawberry in response to different supplemental LED lighting and biofertilizer treatments over three months of observation

Treatments	Fruit number		Fruit weight (g/plant)	
	Nanatsuboshi	KS-75	Nanatsuboshi	KS-75
Control (without BF[1], natural light)	11.67 c	3.50 a	109.93 b	25.55 a
BF, natural light	8.67 a	4.67 a	93.74 ab	40.48 b
Without BF, LED	7.67 a	6.33 b	76.43 a	43.85 b
BF, LED	10.17 b	7.33 b	98.87 ab	56.79 c

Mean values (n=6) followed by different letters in the same column were significantly different according to the Tukey HSD test at $p < 0.05$. [1]Biofertilizer

Regardless of statistical analysis, the number of fruits in Nanatsuboshi fluctuated over the three-month observation period. In the first and third months, all treatments reduced fruit number, whereas in the second month, biofertilizer with natural light and LED without biofertilizer did not affect fruit number. The fruit number of treated plants in the first and third months was 35.8% and 27% lower than the control, respectively. The pattern of fruit number increase in KS-75 was consistent across all months of observation, as evidenced by the positive effects of biofertilizer and LED treatments. The increase in fruit number under LED with biofertilizer was about 130%, 170%, and 53% from the first to the third month, respectively.

The Biofertilizer with natural light and LED without biofertilizer reduced fruit weight in Nanatsuboshi, but biofertilizer application in the LED area maintained the total fruit compared to the control (Table 6). In contrast, all treatments increased the fruit weight in KS-75. The KS-75 grown with biofertilizer under LED lighting during the first, second, and third months had 127%, 166%, and 82% more fruit weight, respectively, compared to the control. The reduced yield in the second month might be due to the lowest PPFD and DLI levels, which are 94.02 mol/m²/s and 8.12 mol/m²/day, respectively. Changes in light that directly affect photosynthesis and carbohydrate allocation to the fruit.

The trend in fruit yield over three months (Table 7) was comparable to the monthly data; a decrease in the number of Nanatsuboshi fruits after treatments was observed. Meanwhile, the KS-75 yield was enhanced by the treatments.

The monthly fruit numbers and weights varied widely because flowers and fruits were not thinned. In general, the Nanatsuboshi was dominated by medium-sized fruit (16-26 g), but the small-sized KS-75 (6-15 g) was the dominant size. The fruit size of Nanatsuboshi is genetically larger than that of KS-75.

Anthesis and fruit set also varied among plants within each treatment, possibly due to differences in plant physiological status and uneven nutrient supply. Moreover, the experiment was conducted on reproductive plants without removing flowers or fruits beforehand. Because strawberry plants naturally vary in their flowering and fruiting stages, they cannot all be harvested at the same time.

Beneficial microbes likely enhance yield by stimulating photosynthesis. The bacteria in the biofertilizer fix nitrogen and produce phytohormones (Hindersah et al., 2021). Spraying beneficial bacteria onto plant shoots growing in soil can improve N status and hence chlorophyll content, photosynthetic rate, and biomass (Efthimiadou et al., 2020). In the phyllosphere, nitrogen and phytohormones are absorbed by leaves through stomata or the epidermis of leaves.

Biofertilizer is applied by foliar spraying, which may alter the phyllosphere microbial composition in Nanatsuboshi, thereby repressing indigenous beneficial microbes. The phyllosphere of Nanatsuboshi may lack essential nutrients needed for fruit development. Some of the sprayed biofertilizer inevitably reaches the growth media. Exogenous bacteria modify the community structure of the rhizosphere and growth media, resulting in a different composition of root exudates that provide nutrients. In the case of Nanatsuboshi, this change may not be suitable for both bacterial and plant growth. However, further research is required to identify the key factors underlying the yield reduction.

A biofertilizer can decrease the yield of a specific strawberry cultivar due to incompatibility with the cultivar, climate, or an unbalanced nutrient profile in the substrate. Microbes often face numerous challenges when introduced into the shoots. Different strawberry varieties respond uniquely to biofertilizers because of their distinct genetics and physiology, and how these interact with the introduced microbes and their activities in providing nutrients. A commercial biofertilizer composed of nitrogen-fixing and phosphorus-solubilizing bacteria slightly decreased the yield of the Dely cultivar but reduced that of Joly (Tomic et al., 2015).

LED lighting significantly impacts yield, both fruit number and yield. Photoperiod, genotype (cultivar), and temperature interact to influence growth and, subsequently, yield, which determines whether growth is vegetative or generative (Bradford et al., 2010). The LED usually increases strawberry yield (Pérez-Romero et al., 2024; Nakayama & Nakazawa, 2023). The results of this study for KS-75 are consistent with the 3.1-fold and 2.5-fold increase in yield of the Nanatsuboshi and Benihoppe cultivars, respectively, under LEDs compared to a conventional subtropical greenhouse (Nakayama & Nakazawa, 2023).

Lower yields might result from unsuitable light intensity, spectrum, or duration for the Nanatsuboshi cultivar, leading to plant stress or nutrient imbalance. Under white LED, strawberry cv Jewel had more severe *Colletotrichum gloeosporoides* than plants grown under ambient light, and all strawberry cultivars showed higher injury rating (Smith et al., 2022). Bacteria in the phyllosphere face alternating environmental conditions, including direct effects of specific LED wavelengths; for example, white LED alters the capacity of Pseudomonas sp. DR 5-09 for substrate utilization (Gharaie et al., 2017).

Light influences plant-microbe interactions by modulating root exudation patterns, which in turn shape the rhizosphere microbiome. Light intensity affects root exudation in the rhizosphere (Martin et al., 2018), and consequently, microbial composition, thereby regulating the nutrient cycle. Increased yield may result from improved nutrient composition in the substrate. Furthermore, light affects phyllosphere microbes and leaf nutrients by altering gene dominance (Kong et al., 2024), thereby altering the availability of nutrients, such as sugars and proteins, on the leaf surface (Larsen et al., 2020).

The strawberry cv. KS-75 responded positively to the LED light and its interaction with Biofertilizer. Nanatsuoshi fruit yield decreased significantly under LED light, possibly because changes in photoperiod and temperature reduced positive plant responses, including microbial

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proliferation and activity in the rhizosphere and phyllosphere. Physiological parameters, including leaf area, nutrient content, and leaf chlorophyll, should be monitored in the following experiment, as all traits directly relate to photosynthesis and carbohydrate allocation to flowers and fruits.

The total soluble solids. Neither biofertilizer in natural light, LED without biofertilizer, nor LED and biofertilizer treatments affected TSS in intact fruit or fruit tips in either Nanatsuboshi or KS-75 (Tables 8 and 9). Over three months, TSS remained constant for both varieties. Without statistical analysis, the TSS of intact fruit was likely lower than that of the fruit tip, since sugar in strawberries usually accumulates in the fruit tip. The TSS of Nanatsuboshi was lower than that of KS-75, even though the yield of Nanatsuboshi was higher than that of KS-75 (Table 7). In general, the TSS of intact fruit of both cultivars, mainly KS-75, was higher than that of the local strawberry (Romiyadi & Putri, 2024). However, the TSS of both cultivars agrees with that of local strawberries grown with humic acid and biofertilizer-coated fertilizer (Hindersah et al., 2023).

The fruit tip of strawberries is usually sweeter than the rest of the fruit because maturity begins at the tip. The TSS of KS-75 is higher than that of Nanatsuboshi. The TSS increases in intact fruit were more pronounced in KS-75 following biofertilizer inoculation. Fruit sweetness is directly determined by leaf sugars, which are generated during photosynthesis and serve as the primary source of sugars accumulated in the fruit. This preliminary experiment did not reveal a direct effect of LED, biofertilizer, or their combination on photosynthesis.

Sugar transport and accumulation directly require potassium, boron (B), and P. Biofertilizers did not affect sweetness, possibly because phosphate-solubilizing bacteria did not supply sufficient P for sugar transport. Furthermore, B might precipitate in the medium due to phosphate binding. The white LEDs used in this study may be less effective than blue LEDs, which increase sugar (sucrose and fructose) production (Hwang et al., 2025).

Table 8. Total soluble solids of 'Nanatsuboshi' and 'KS-75' strawberry intact fruit in response to different supplemental LED lighting and biofertilizer treatments over three months of observation

Treatment	TSS of intact fruit (°Brix) in each month					
	Nanatsuboshi			KS-75		
	1st	2nd	3rd	1st	2nd	3rd
Control (without BF[1], natural light)	8.7 a	8.5 a	8.5 a	8.7 a	9.3 a	9.2 a
BF, natural light	8.5 a	8.9 a	8.9 a	9.2 a	9.8 a	9.9 a
Without BF, LED	8.3 a	8.9 a	8.7 a	9.5 a	9.3 a	9.6 a
BF, LED	8.4 a	8.7 a	9.1 a	9.5 a	9.6 a	9.6 a

Mean values (n=6) ± standard deviation followed by different letters in the same column were significantly different according to Tukey HSD test at $p < 0.05$. [1]Biofertilizer

Table 9. Total soluble solids of 'Nanatsuboshi' and 'KS-75' strawberry tip fruit in response to different supplemental LED lighting and biofertilizer treatments over three months of observation

Treatment	TSS of Tip Fruit (°Brix) in each month					
	Nanatsuboshi			KS-75		
	1st	2nd	3rd	1st	2nd	3rd
Control (without BF[1], natural light)	9.2 a	9.0 a	9.1 a	9.1 a	9.7 a	9.6 a
BF, natural light	9.0 a	9.8 a	9.5 a	9.6 a	10.4 a	10.3 a
Without BF, LED	9.5 a	9.4 a	9.3 a	10.0 a	9.6 a	10.1 a
BF, LED	9.0 a	9.4 a	9.80 a	10.0 a	9.5 a	10.1 a

Mean values (n=6) ± standard deviation followed by different letters in the same column were significantly different according to the Tukey HSD test at $p < 0.05$. [1]Biofertilizer

The research limitations were that the flowers and fruit were not removed beforehand, resulting in inconsistent fruiting status among plants and non-simultaneous harvest times. Further experiments should also include physiological parameters such as chlorophyll content and the uptake of essential macronutrients and specific micronutrients that regulate photosynthesis. Despite the results of this experiment, strawberry cultivation in greenhouses in Indonesia using biofertilizers remains promising. However, the limitations of the experiment described above need to be addressed.

Conclusion

This study successfully characterized the microbial and biochemical properties of the liquid consortia biofertilizer, which met the Indonesian biofertilizer quality standards and contained high populations of N-fixing and P-solubilizing microbes, as well as plant-growth-related phytohormones such as IAA, gibberellins, and cytokinins. The evaluation of its effectiveness under controlled greenhouse conditions demonstrated that the two Japanese strawberry cultivars responded differently to the biofertilizer and LED treatments. Biofertilizer and LED lighting consistently enhanced fruit number, total fruit weight, and TSS in cv. KS-75, indicating strong compatibility with both inputs. In contrast, Nanatsuboshi exhibited a reduced number of fruits under biofertilizer and LED treatments, although its fruit-tip TSS remained unchanged. However, biofertilizer application in the LED area maintained the fruit weight compared to the control. These findings highlight a significant interaction between cultivar, biofertilizer, and supplemental lighting, suggesting that KS-75 is better suited for integrated biofertilizer–LED cultivation systems in tropical greenhouses.

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